

# Bringing the Cloud to Rural and Remote Areas – Cloudlet by Cloudlet

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## Abstract

Instead of relying on huge and expensive data centers for rolling out cloud-based services to rural and remote areas, we propose a hardware platform based on small single-board computers. The role of these micro-data centers is twofold. On the one hand, they act as intermediaries between cloud services and clients, improving availability in the case of network or power outages. On the other hand, they run community-based services on local infrastructure. We illustrate how to build such a system without incurring high costs, high power consumption, or single points of failure. Additionally, we opt for a system that is extendable and scalable as well as easy to deploy, relying on an open design.

## 1 Introduction

Cloud computing is a disruptive technology that has already changed the way many people live and conduct business. Clearly, individuals, organizations, and businesses in developing countries are also adopting services such as reliable data storage, webmail, or online social networks. However, according to a report by the United Nations Conference on Trade and Development (UNCTAD), the rate at which this adoption takes place is much slower [24].

In Western countries the increasing demand by users is met by creating ever-larger data centers and upgrading and extending high-speed communication networks. In developing countries the picture looks different. The UNCTAD report goes on saying that missing infrastructure is a major obstacle for the uptake of cloud computing in these regions [24]:

[...] whereas there were in 2011 more than 1000 secure data servers per million inhabitants in high-income economies, there was only one such server per million in [the least developed countries (LCDs)].

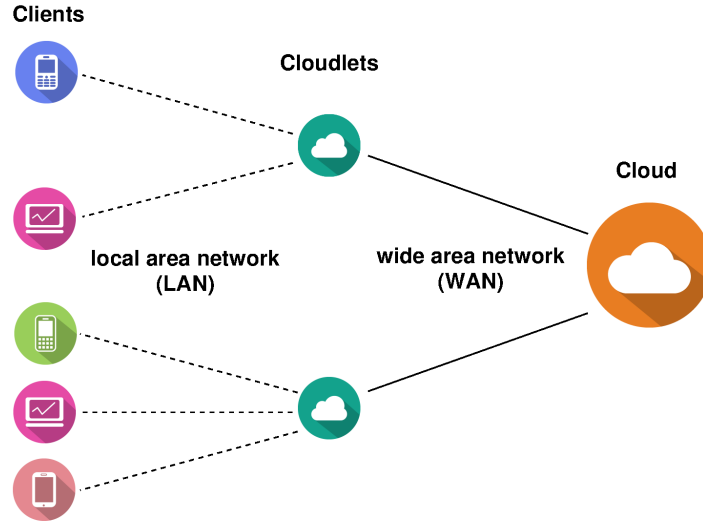


Figure 1: Cloudlet architecture

We argue that trying to copy the infrastructure of Western countries is neither feasible nor meets the requirements of developing countries, since setting up and maintaining a number of large data centers can easily cost hundreds of millions of dollars. Just using the infrastructure provided by the large multinational corporations that create such data centers is also not an ideal situation. Handing over data to foreign entities raises all kinds of issues ranging from privacy and data protection (the local laws and regulations may not match those of the hosting country) to national security and industrial espionage.

Additionally, due to network outages it may be difficult to establish reliable access to these remote servers, which is an even more acute problem for rural areas. Then moving to the cloud to gain a reliable storage solution would be negated by not being able to access it at all times. Consequently, we advocate the use of small, distributed data centers that can be adapted to the local needs in a bottom-up, community-based fashion. These can serve as hubs and relays for (large-scale) remote cloud services or as facilities for local community services. Pushing some of the data storage and computation to the client side is known as a *cloudlet* architecture [11, 18, 25], and is done to improve the availability and durability of stored data, as well as to lower network latencies in mobile devices. Figure 1 shows a typical cloudlet architecture: the clients are not directly connected to the cloud but via cloudlet servers.

It is important that the design of cloudlet data centers considers the specific requirements of developing countries. First of all, it has to use low-cost components that are readily available. Second, low power consumption is a crucial criterion. Due to unreliabilities in the provision of electricity, the data center may have to be run on solar power or batteries for considerable stretches of time. Third, we need a robust and sustainable system than can be operated in a harsh environment (in terms of temperatures and weather). Finally, the data center should be based on open platforms and standards and avoid proprietary technology as much as possible. This will make it easier to de-

ploy, maintain, and repair the hardware. Additionally, an open system allows users to adapt, extend, and scale it to their particular needs. Interestingly enough, even a big player like Facebook is advocating the use of open hardware in their Open Compute Project initiative [19].

Here we illustrate how single-board computers, such as the Raspberry Pi (RPI), can serve as building blocks for computing platforms that meet the requirements described above. Originally developed to spark the interest of school children in computer science, it has also been discovered by hobbyists worldwide, who use it for a wide range of projects. We have been building Raspberry Pi clusters and experimenting with them for more than two years now. A while ago we have started using them for teaching and training purposes and even as a testbed for research. We believe that this technology has a lot of potential and can make an impact on the lives of many more people by serving as a low-cost data storage and computing platform.

The remainder of the paper is structured as follows. We discuss related work in the next section and then describe our hardware design in Section 3, followed by a brief discussion of software aspects in Section 4. Section 5 highlights and explains some of our design decisions in more detail and also sketches use cases and application domains. Finally, in Section 6 we conclude with a brief summary.

## 2 Related Work

There are many studies investigating the adoption of cloud computing, for some overview and survey papers, see [4, 6, 21].<sup>1</sup> However, most of these studies highlight the topic from the point of view of well-developed countries. While some inhibitors, such as security and privacy concerns, hold universally [20], others are predominantly found in developing countries and play almost no role in Western countries [2, 7, 12]. Predominant among these are unstable power grids and inadequate internet connectivity, translating into more or less frequent outages. This calls for a different approach to cloud computing: before cloud services can take off, a reliable infrastructure has to be put in place.

There are numerous publications on connectivity, communications networks, and bandwidth, see [3, 10, 13, 14, 16, 17] for a few examples. While the networking aspect is very important, the storage and computational aspects should not be neglected; especially since getting the infrastructure for widespread broadband connectivity into place will still take considerable time. Consequently, there is a need for local data centers that can bridge the communication gaps. Tesgera et al. propose a cloudlet-based approach to tackle network issues in emerging regions, but do so very briefly on a very abstract level, identifying research challenges, but not proposing any implementation [22].

We agree with Hosman and Baikie [9] that the Western “bigger is better” approach for building large-scale data centers is bound to fail in developing countries, due to the particular constraints. Furthermore, in a study Hosman identifies the main challenges faced by hardware deployers in these regions [8]: energy consumption, cost, environment-related issues, connectivity, and maintenance and support. These are all crucial aspects we cover by relying on inexpensive, low-power, rugged platforms, such as micro-computers, to build micro-data centers.<sup>2</sup> There are various groups already

<sup>1</sup>Actually, two of the co-authors of this paper were involved in a recent study [15].

<sup>2</sup>This approach is also indicated in [8, 9].

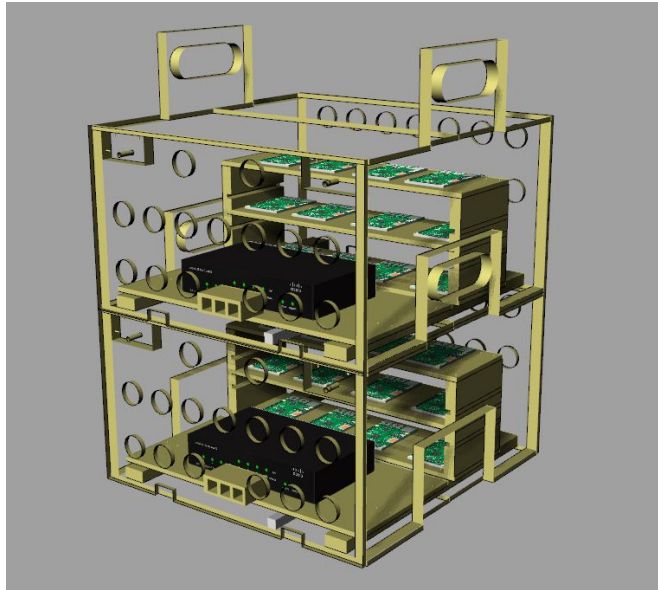


Figure 2: Stacked boxes

working on developing Raspberry Pi clusters and similar architectures [1, 23], the challenge is to adapt these designs to the conditions found in developing countries.

### 3 Hardware

In the following we give an overview of the hardware employed in our design: in particular the casing, network architecture, electronic components, power supply, and cooling.

#### 3.1 Casing

At the core of our design are modular wooden stackable boxes of size 40 x 40 x 25 cm (shown in Figure 2), offering several advantages. The boxes can be assembled and disassembled with a simple screw driver and for transport the individual parts can even be stored in (hand) luggage. Once set up, the contents of a box can be accessed without the need for any tools. The front plate is fixed with wing screws, which can be opened with bare hands. The boxes also feature handles, which allows their transport in assembled state. Additionally, the electronic components are not soldered to the casing, but fixed on shelves with screws. Consequently, the devices inside of a box can be easily accessed, repaired, substituted, maintained, and updated, even by a person with minimal technical skill. For the casing we have chosen wood, because it is an environmentally friendly material that can be found around the world. However, this can be replaced with material that is readily available locally.

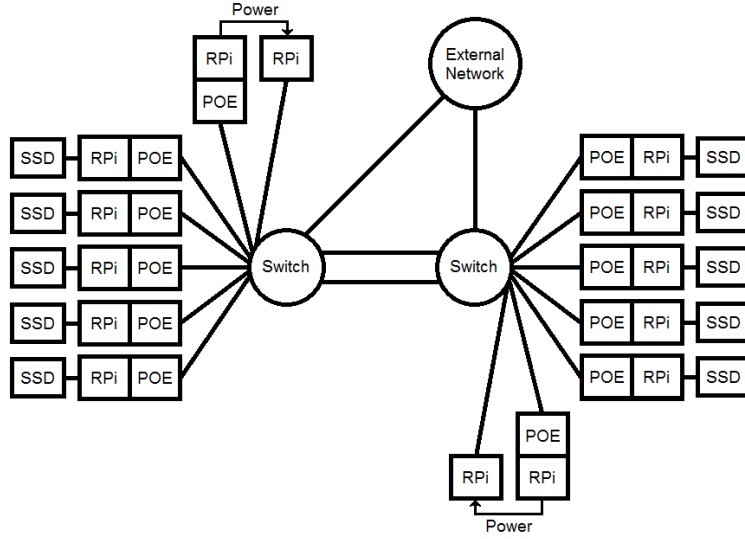


Figure 3: Network architecture

### 3.2 Network Architecture and Components

The default network architecture consists of two subclusters connected via two switches, which in turn can be connected to an external network. Figure 3 shows a schematic diagram of the architecture. (We use 8-port switches with two additional uplink ports; PoE stands for Power over Ethernet and will be discussed later). A subcluster, which fits into one box, comprises two control and five data storage/computational Raspberry Pis, to which solid state disks are connected. By running two subclusters each containing multiple RPIs, we avoid a single point of failure, in case of a breakdown the data center can be kept up and running, albeit at reduced performance. This design is also scalable: we do not need to connect both switches to the external network, one of them can also be connected to one or more other subclusters.

In our current design we use the new Raspberry Pi 2, model B, with a 900 MHz quad-core ARMv7 CPU and 1GByte RAM, as it exhibits a higher performance than its predecessor, the Raspberry Pi B+. However, it has a slightly higher power consumption than the B+ model, even in single-core mode. Thus, if power consumption is a crucial issue, the Pi 2 can be swapped for the Pi B+. In terms of costs, the difference between the two models is about \$10, the Raspberry Pi 2 currently sells for around \$35, the B+ model for \$25.<sup>3</sup> In fact, we are not restricted to Raspberry Pi boards, other single-board computers, such as Banana Pi, Odroid or any other device with a CPU of the ARM family would also work. With some tinkering it would even be possible to make use of old smart phones.

Using the power over ethernet (PoE) technology simplifies the assembly, as we do not need separate sets of cables for communication and power supply. Additionally, it eliminates the need for separate power supply sockets for the Raspberry Pis, although a

<sup>3</sup>Clearly, there are additional costs for building the whole cluster, such as for the switches, solid-stage storage, batteries, cables, and so on. These very much depend on the size of the cluster.

PoE adapter is necessary on the RPi side. The main advantage, though, is the provision of smart power management and monitoring techniques integrated into the system. For example, when using the HP 2530-8-POE+ switch, PoE operation can be disabled and enabled (at different levels of priority) for each individual port. Clearly, this configuration has a price tag attached to it: a solution relying on PoE will add to the costs of the system. We can make a marginal saving by connecting the two controller RPis of a subcluster via a single PoE adapter for supplying them with power.

### **3.3 Power Supply**

The power supply, which requires a separate box, comprises four 12V Lithium or lead-acid batteries configured in series with a total capacity of 200 Ah. The batteries, whose task it is to provide a constant source of energy, can be charged via solar panels or any other source of electricity that is available. The lead batteries have the advantage of being cheaper than the Lithium ones. However, the Lithium batteries are much better suited to higher temperatures and will degrade much more slowly under these conditions. The lead batteries should not be ruled out completely, though. In a high-altitude environment, such as the Andes or the Himalayas, we may run into problems with Lithium batteries and low temperatures, as they cannot be charged at temperatures below freezing. Thus, lead batteries would be a better choice for these regions. The power management is controlled by a power inverter and battery charging regulator. In our prototype, a 220V AC 300W sine wave power inverter (Studer AJ-400-48) and a Lithium battery charger is used. When using lead batteries, we can replace this with the AJ-400-48-S model, which also integrates a 10A 48V DC lead-acid battery charging regulator. The AC output socket from the power inverter can be extended by a three-way power strip to supply a laptop or other external diagnosis tool.

### **3.4 Cooling**

An important design decision is to use only passive cooling techniques, so that we do not incur any additional power consumption and that there are no moving parts that can break down. We created a set of holes on two opposite sides of the casing to make use of the stack effect for cooling. One set of holes is found in the upper part of one side, while the opposite set is located in the lower part. The warm air flows out through the upper set, drawing in cooler outside air through the lower set. For protection, the holes can be covered with anti-insect and anti-dust nets. Depending on the placement of the boxes, additional cooling mechanisms can be put into place, such as solar chimneys, windcatchers, or making use of the cooler temperature underground by installing additional heat sinks.

## **4 Software**

In our group we developed tools to set up and maintain the operating system installed on the individual nodes of the data center. We do this in an efficient and automated manner with scripts that install a minimal version of Debian or ArchLinuxARM on a node, register a node in the cluster, and then update the node to fully integrate it into the cluster. We can also monitor the activity of each node by installing our monitoring panel. This covers the basic infrastructure, but is not enough yet. A cluster in which software is deployed in a bare-metal fashion on individual nodes is not attractive

for potential users, some form of middleware is needed. However, most off-the-shelf solutions, such as OpenStack or similar frameworks, are usually too heavyweight for Raspberry Pi clusters.

The storage manager component of OpenStack, Swift, is relatively lightweight compared to other components, such as Nova (computing) and Neutron (networking). We have successfully deployed it on a Raspberry Pi cluster, making the cluster usable as a data storage platform with data replication, meaning that we do not lose data in case of (partial) hardware failure. Currently, we are working on extending this solution to other aspects of cloud computing.

## **5 Discussion**

In the following we provide more details and motivate some of the particular design decisions we made. We also discuss application domains of our server architecture.

### **5.1 Scalability/Open Hardware and Software**

While we were designing our data center we realized that it would be crucial to already anticipate some of the future requirements or changes that users would make to the system to adapt it to their needs. That is the reason why we went for a flexible design around the core of wooden boxes housing the electronic devices. Depending on the specific requirements in terms of power consumption, redundancy, and computational power, a suitable number of boxes containing electronics and power supplies can be selected and stacked on top of each other.

### **5.2 Power Consumption**

In a test run, we measured the power consumption of one box, i.e. one subcluster with seven Raspberry Pis, a switch, and five SSDs. Generating a stress test under ArchLinux with two CPU processes, one IO load, and one RAM load with 128MB malloc as a benchmark, one subcluster consumed 48W running the benchmark.

We specified the capacity of the batteries assuming a load that continuously consumes 96W (for the two subclusters). The goal was to keep the discharge rate at 50% for a duration of twelve hours. Regularly discharging down to low levels has a detrimental effect on the life of the batteries. A duration of twelve hours was chosen to be able to run the data center over night, during which there is no sunlight for solar panels. Nevertheless, the capacity of the batteries can be adapted to the local circumstances.

### **5.3 Use Cases**

Our goal is not to compete with the high-tech environment usually found in large cities and metropolitan areas, but to provide an alternative for more rural areas. The proposed approach allows users to set up local servers which can be used as components of a private or community cloud network. This is especially important when it comes to handling sensitive data in domains such as health care and governance, as it gives full ownership of the data and services to the persons running the data center. Other important use cases are education and research. As we have experienced with our own students, it is an ideal platform for teaching practical skills in the area of distributed

systems. The acquired knowledge ranges from hardware all the way to protocols synchronizing nodes in a network. Due to its mobility it can also be used to set up field labs for processing data, which, for example, is generated by sensor networks monitoring the environment. Beyond these applications, the platform may even help in sparking entrepreneurial activity, as the initial investment is not large and the system can be scaled out when and if the need arises. Moreover, upgrading the system with more efficient boards as they become available can be done gradually, i.e., this does not have to be done in one go, making it possible to achieve the upgrade with a number of smaller investments rather than one big one.

## 6 Conclusion and Outlook

Even though cloud computing and similar services are also expanding in developing countries, they are still far from being widely spread. While there are also discussions about factors inhibiting the adoption of cloud computing in Western countries, there are factors which are unique to the developing world, so trying to apply the Western approach to cloud computing is very likely bound to fail. Two crucial factors, which were also identified in a report by the World Economic Forum [5], are the lack of both infrastructure and a skilled workforce. We believe that our micro-data center architecture can start filling these gaps by providing an open, inexpensive, adaptable, and extendible platform with a low power consumption, empowering communities to take matters into their own hands. Due to these features, it can also be rolled out in schools and universities to teach and grow the next generation of engineers and computer scientists.

We hope that in the near future the digital divide will not widen, as it is currently doing in the area of cloud computing, but become narrower. However, we believe that in order for this to happen, it is not sufficient for developing countries to just import information technology. Ultimately, a lot of the needed infrastructure should be developed and produced in the countries themselves. In that light, we see our cluster as a starting point for many more creative and innovative solutions.

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